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March 29, 2012

James Ball
International Bureau
Chief – Policy Division
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: Petition for Rulemaking To Establish A Next Generation Air-Ground Service On A Secondary Licensed Basis In The 14.0 to 14.5 GHz Band, RM-11640

Dear Mr. Ball:

QUALCOMM Incorporated ("Qualcomm") is pleased to provide the attached response to several follow-on items and questions that FCC staff raised in a March 8, 2012, meeting wherein Qualcomm and the Commission discussed Qualcomm's January 30, 2012, filing relating to the above-referenced Petition for Rulemaking.

Qualcomm encourages the FCC to issue a Notice of Proposed Rulemaking very soon proposing to establish the Next Generation Air-Ground service on a secondary licensed basis in the 14.0 to 14.5 GHz band. Qualcomm has invested substantial resources developing next generation air-ground broadband technology, and the company is prepared to invest in and support the deployment and operation of a highly robust network to enable such airborne connectivity. Thus, Qualcomm is eager to bring next generation air-ground broadband technology to air travelers across America and looks forward to continuing to work with the FCC and all interested stakeholders during this rulemaking.

Respectfully submitted,

Dean R. Brenner
Vice President, Government Affairs

Att.

cc (via email): Kathleen Collins
Thomas Derenge
Peter Georgiou
Howard Griboff
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Paul Locke
Robert Nelson
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Attachment – Qualcomm Follow-on Responses to FCC Staff Technical Questions

1. Cell Splitting

The FCC IB January 19, 2012, letter asked: [G]iven that the distribution of aircraft is not uniform and the number of aircraft per square mile can be significantly higher over certain airports, how will you compensate for this uneven aircraft distribution to ensure no FSS satellite receiver will receive more than the calculated interference?

By operating with as many as 250 cell sites across the CONUS and in approximately 500 MHz of spectrum, the Next-Gen AG system can provide a large amount of capacity that will adequately service aircraft in all regions of the CONUS and support new bandwidth hungry devices and streaming services. However, if over time, the number of aircraft, the uptake of the service, and bandwidth demand of devices increase, and there is a need for even more capacity, the Next-Gen AG system can increase capacity without any increase in interference as explained below.

The network layout is modified by adding new GS sites to accommodate an uneven aircraft distribution while maintaining adequate coverage. To accomplish this goal without increasing the total interference to GSO satellites, the EIRP needed by the new sites is taken from the EIRP of neighboring sites so that the total EIRP from any region of CONUS remains the same.

Consider, for example, a hexagonal layout of 64 GSs in an 8 x 8 square (as shown in Figure 1). The nominal GS spacing is 250 km as described in the Petition, which is also the dimension of each square. Each GS covers an angular region of $\pm$ 60 degrees out to a radial distance of 300 km for an aircraft at 10 km (or 39,000 ft) altitude. This layout sufficiently covers the inner 7.5 x 7.5 square region in the grid with an assumed aircraft density ρ.

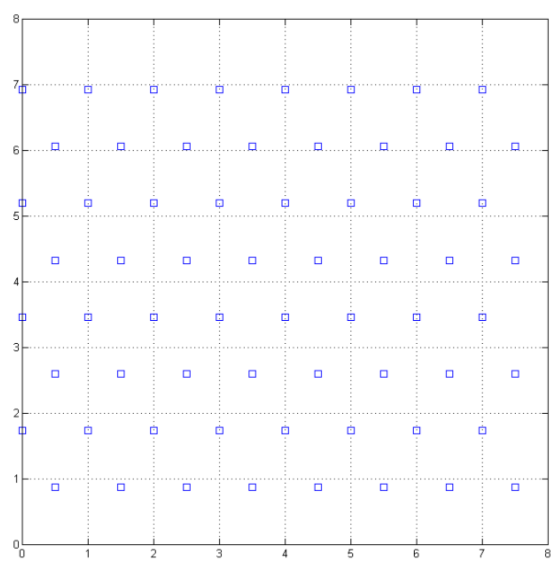

Figure 1. 8 x 8 Hexagonal Layout. 1 Unit = 250 km

Now suppose the lower right 4 x 4 square region is a region with twice the aircraft density, 2ρ. If the standard layout is not able to provide sufficient capacity to handle the increased traffic in the lower right square region, the Next-Gen AG network may be enhanced through "cell splitting". This may be accomplished by doubling the density of GSs in this region. Referring to Figure 2, the 4 x 4 region that originally contained 16 GSs (in blue) is now served with 36 GSs (in red), with a site-to-site separation reduced by a factor of approximately $1/\sqrt{2}$. In other words, in this more dense cell configuration, the site-to-site spacing has been reduced from 250 km to 175 km and the coverage radius has been reduced from 300 km to 212 km. The new layout is shown in Figure 3, with the higher density sites depicted in red to distinguish them from the standard sites in blue.

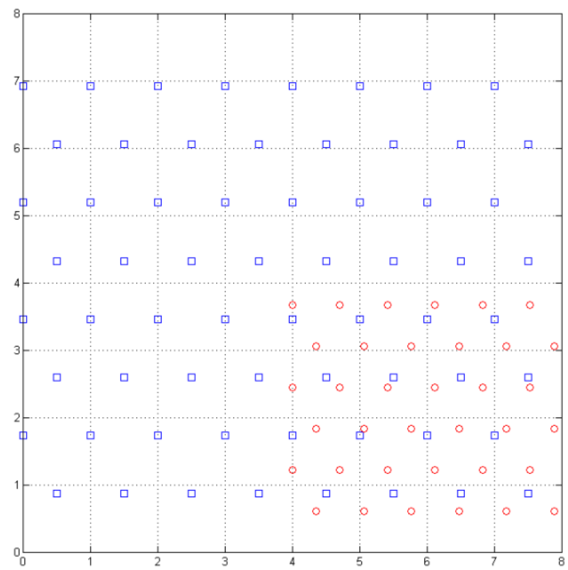

Figure 2. 8 x 8 Hexagonal Layout With Locally Overlayed Cell Sites

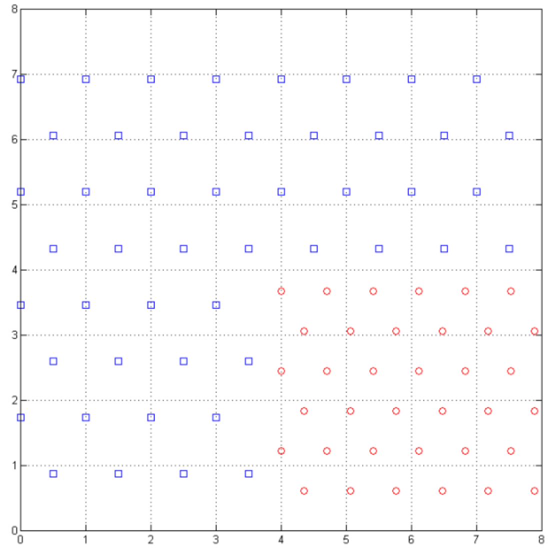

Figure 3: 8 x 8 Modified Layout to Handle Increased Traffic In Lower Right Region

Because the number of sites in the lower 4x4 square region has increased from 16 to 36, in order to hold the overall interference power to the geo-arc fixed, the transmit power of each red site is decreased by a factor of 36/16 = 3.5 dB. The transmit power for the remaining original blue sites are not modified, so their coverage areas and overall capacity remain virtually unchanged.[1]

Since the transmit power of the red sites has been reduced by 3.5 dB, it is necessary to confirm that the modified layout achieves the desired goals of coverage and capacity on both the forward (ground-to-air) and reverse (air-to-ground) links in the 4x4 lower right square region. The forward and reverse coverage is discussed below in Sections 1.1 and 1.2, and the effect on capacity is discussed in Section 1.3.

1.1 Forward Link Coverage:

As mentioned above, for an aircraft at a 10 km altitude, the cell edges for a red site and blue site are at a distance of 212 km and 300 km, respectively. Also, an aircraft at 10 km altitude appears at a slightly higher elevation angle at a distance of 212 km than at 300 km (2 degrees instead of 1 degree, assuming a GS height of 100 m above sea level). Therefore, the elevation angle coverage required from a red site is different from that of a blue site. Unlike a blue site where the antenna must cover elevation angles down to 1 degree, a red site antenna needs only cover elevation angles of 2 degrees and higher. Accordingly, the red site uses a modified antenna with the same peak gain as that of the blue site's antenna, but whose main lobe peaks at an elevation angle of 2 degrees instead of at 1 degree. Of course, the antenna for the smaller cells will have the 0 dBi peak backlobe gain as described in the Petition, but the total power transmitted toward the geo-arc is reduced by 3.5 dB due to 3.5 dB reduction in the transmit power from the GS.

[1] There may be minor changes in the coverage regions of blue sites along the boundary separating the blue sites from the red sites, but this will not have a material effect on overall system coverage.

Thus, decreasing the transmit power of a single red site by 3.5 dB directly reduces the potential interference radiated to the geo-arc by the same factor of 3.5 dB.

To determine the change in the cell-edge C/N, note that the following additional losses in the link budget are reduced for a red site:

1. Reduced Path Loss – since the slant range to the cell edge is reduced by a factor of $1/\sqrt{2}$, the free-space path loss is reduced by 3 dB.

2. Reduced Atmospheric Losses – since the cell-edge propagation distance is reduced by about 90 km (*i.e.*, 212 km vs. 300 km), the losses due to atmospheric water vapor and oxygen absorption are reduced by about 0.9 dB.[2]

The link budgets for cell-edge coverage for the 300 km and 212 km cell sizes are compared in Table 1. The C/N at the cell-edge in these two cases is 10.2 dB and 10.6 dB, respectively. Observe that despite reducing the transmit power for a red site by 3.5 dB, the cell edge C/N improves by 0.4 dB.

	300 km, 1 deg EL		212 km, 2 deg EL	
Tx Power into Antenna (per beam, 50 MHz)	2.5	dBW	-1	dBW
Antenna Gain (Design Goal)	37	dB	37	dB
Path Loss at 14 GHz	-164.9	dB	-161.9	dB
Ku-band Atmospheric Losses	-3	dB	-2.1	dB
Polarization Mismatch	0	dB	0	dB
Aircraft Antenna G/T	-13	dB/K	-13	dB/K
1/BW (BW = 50 MHz)	-77	dB-Hz	-77	dB-Hz
1/Boltzmann Constant	228.6	dB/K-Hz	228.6	dB/K-Hz
C/N at Cell Edge	10.2	dB	10.6	dB

Table 1. Link Budgets for Forward Link Coverage for Original and Small Cells

1.2 Reverse Link Coverage:

Since the lower right 4x4 square region in Figure 3 now contains twice as many aircraft as before, the aircraft in this region must reduce their EIRP by a factor of 3 dB when communicating with red sites. This ensures that the total interference radiated to the geo-arc is not increased by a doubled aircraft density. In practice, the reduced power can be enforced by means of reverse link power control from the red site GSs.

Next, it should be verified that reducing the transmit EIRP from aircraft does not affect the reverse link coverage. Similar to the forward link, a red site has a reduced reverse link coverage radius of 212 km, compared to 300 km for a blue site. Accordingly, the following losses on the reverse link are reduced:

[2] Louis J. Ippolito, "Propagation Effects Handbook for Satellite Systems Design: A Summary of Propagation Impairments on 10 to 100 GHz Satellite Links with Techniques for System Design," NASA Reference Publication 1082 (04), 1989.

1. Reduced Path Loss – since the slant range to the cell edge is reduced by a factor of $1/\sqrt{2}$, the free-space path loss is reduced by 3 dB.
2. Reduced Atmospheric Losses – since the propagation distance is reduced by about 90 km to the cell edge, the losses due to atmospheric water vapor and oxygen absorption are reduced by about 0.9 dB.[3]

Also note that since the red site's antenna gain pattern has been modified to peak at 2 degree elevation instead of at 1 degree elevation (*see* Section 1, *supra*), the red site GS G/T remains unchanged at 8 dB/K for communicating with an aircraft at its cell edge (212 km, 2 degree elevation). After accounting for these factors, the resulting link budget contrasting the 300 km and 212 km cell sizes is shown in
Table 2.

	300 km, 1 deg EL		212 km, 2 deg EL	
Aircraft EIRP in 2 MHz	3	dBW	0	dBW
Path Loss at 14 GHz	-164.9	dB	-161.9	dB
Ku-band Atmospheric Losses	-3	dB	-2.1	dB
Polarization Mismatch	0	dB	0	dB
GS G/T	8	dB/K	8	dB/K
1/BW (BW = 2 MHz)	-63	dB-Hz	-63	dB-Hz
1/Boltzmann Constant	228.6	dB/K-Hz	228.6	dB/K-Hz
C/N at Cell Edge	8.7	dB	9.6	dB

Table 2. Link Budgets for Reverse Link Coverage for Original and Small Cells

A key observation is that despite reducing the aircraft EIRP by 3 dB, the C/N at the cell edge is improved by 0.9 dB.

1.3 Increased System Capacity

The reason for replacing 16 blue sites with 36 red sites is to increase the system capacity in the lower 4x4 square region in order to service twice as many aircraft as the other regions. It is important to ensure that aircraft communicating with a red site achieve a minimum level of performance (*e.g.*, data rate exceeding a certain minimum) comparable to when they communicate with a blue site. Since the red site GSs transmit with 3.5 dB less power, this may seem difficult. However, this can be achieved through a combination of system optimizations and operational tradeoffs, as described below:

1. The red site's antenna pattern needs to be optimized. First, the antenna's main lobe is steered upward in elevation so that it peaks at 2 degrees instead of 1 degree, to account for the smaller coverage radius. Second, the antenna's radiating aperture needs to be "taller" to have a more tightly shaped pattern (and therefore gain) in elevation. Taken together, the antenna designed for

[3] Louis J. Ippolito, *supra*.

the smaller cells has increased gain by 3 dB at the 2 degree elevation angle,[4] and by about 2 dB at the 10 degree elevation angle, compared to the nominal antenna design appropriate for a blue GS site. Note that the 2-10 degree elevation angle range is over 90% of the coverage area for a red GS site. Aircraft at higher elevation angles can be better served from more distant sites where they appear at lower elevation angles, because the greater path loss is more than offset by the increased antenna gain at lower elevation angle. In fact, the tighter clustering of red sites creates potentially more overlapping coverage zones that can be exploited in this way.

2. Recall that the link budget analysis revealed an extra 0.4 dB and 0.9 dB margin in C/N, for the forward and reverse links, respectively, for aircraft near the edge of coverage of red sites. Thus, the transmit power in beams to such aircraft can be reduced by about 0.4 dB without affecting their performance, while at the same time an offsetting increase in transmit power can be delivered to aircraft in less advantageous locations, *i.e.*, at elevation angles with less than ideal antenna gain. In this way, the excess margin for some aircraft can be used to "equalize" performance across aircraft irrespective of their location in the coverage area. An analogous technique can be used to equalize performance across reverse links.[5]

By optimizing the red GS site's antenna pattern and "equalizing" transmit power across beams and aircraft to compensate for a less than ideal antenna pattern, after cell-splitting (despite the 3.5 dB transmit power reduction from a red GS) the C/N for any aircraft in the lower 4x4 square region is reduced by no more than approximately1 to 1.5 dB[6] compared to the original configuration where it was served from a blue GS site. Similarly, despite the 3 dB EIRP reduction for an aircraft, the C/N achieved on the reverse link is no more than about 1.5 dB worse than the original configuration where it was communicating with the nearest blue GS. Of course, most of the airplanes served by a red site will experience virtually no reduction in their C/N; the ~1 to 1.5 dB reduction is experienced by aircraft at unfavorable elevation angles where the antenna gain may fall short of ideal.

Because the required C/N to achieve the target bandwidth efficiency of 1 bit/second/Hz is 4 dB as discussed in the Petition, and because the achieved C/N is on the order of 10 dB or better for the forward link, and 8 dB or better for the reverse link, aircraft that experience a 1 to 1.5 dB reduction in C/N only suffer a corresponding 1 to 1.5 dB loss in link margin; hence, there is no impact on their target bandwidth efficiency of 1 b/s/Hz. Thus, by doubling the number of cell sites through cell splitting, the effective number of aircraft that can be simultaneously served also is doubled, with no increase in radiated potential interference towards the geo-arc.

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[4] The nominal blue GS site antenna peaks at 1 degree and has a 3 dB rolloff between 2 degrees and 1 degree. Therefore, steering the main lobe to a 2 degree elevation produces the desired 3 dB additional gain at 2 degrees. To produce more antenna gain between 2 and 10 degrees requires a taller antenna with pattern shaping.

[5] During our most recent meeting with the FCC staff, Qualcomm suggested one possible means of controlling potential interference from additional sites on which the agency may want to seek comment in the NPRM. A Next-Gen AG system operator can be authorized to operate its system with certain number of sites, each operating with a maximum power level, etc., and if the operator wants to add one or more GSs to support increased capacity (*i.e.*, cell splitting) the FCC could require the operator to provide a showing of non-interference based upon the location/power level/etc of the new sites.

[6] The transmit power has dropped by 3.5 dB and the antenna gain for the 2-10 degree elevation angle range has been increased by 2-3 dB. Therefore, the C/N changes by -3.5 dB + 2 dB = -1.5 dB at worst.

2. Peak to Average Question

The FCC IB January 19, 2012, letter asked: Is your interference analysis based on peak or average power? If it is based on average power, please inform us of your expected peak-to-average power ratio.

Qualcomm's January 30, 2012, filing stated that the Next-Gen AG signal as seen by the satellite uplink has a Gaussian distribution and will appear as additive white Gaussian noise (which models thermal noise) to the satellite uplink, and thus has the same effect on the satellite uplink receiver as thermal noise. In other words, in order to assess the impact of the Next Gen AG signal to the satellite uplink, the average power of the Next Gen AG system as seen by the satellite uplink must be considered. Qualcomm is pleased to provide additional information on the properties of the Next Gen AG signal as seen by the satellite receiver.

The Next-Gen AG system employs a wideband pulse modulated waveform for data transmission. Within any spectral window of narrower bandwidth, the total interference seen by a satellite receiver is the sum of thermal noise and multiple wideband interfering signals from the Next-Gen AG GSs and aircraft. In the conservative interference calculation set out in the Petition, it was shown that the average power of the interfering signals in any spectral band amounted to less than 1 percent of the thermal noise power in that band. The following discussion explains that, additionally:

1. The total interference (thermal noise plus Next-Gen AG interference) is spectrally white in any bandwidth window, *see* Section 4.1 below;

2. Samples of the interference random process produced by a single GS beam are approximately Gaussian distributed, *see* Section 4.2 below;[7]

3. Samples of the interference random process produced by a superposition of multiple beams from multiple GSs are approximately Gaussian distributed, *see* Section 4.3 below. In fact, the interference random process is well approximated as a Gaussian random process;

4. Combining points 1-3 above, the total interference process (thermal noise plus interference) is effectively a white Gaussian noise process, *see* Section 4.4 below. Hence, the effect of the interference on a narrow bandwidth satellite channel is to raise the thermal noise floor by the average interference power. The peak-to-average ratio of the interference is the same as the peak-to-average ratio of the thermal noise, and is therefore inconsequential.

The Next-Gen AG system employs an OFDM waveform for forward link transmission. The forward link waveform will not employ frequency hopping nor will it use a "flash" signal. Also, in any given GS beam, all tones allocated in a frequency channel (e.g., 20 MHz or 50 MHz) will be employed with power distributed uniformly across all tones, so the transmitted waveform is "flat" across the allocated frequency channel. These restrictions ensure that during the period when the GS is transmitting, the radiated waveform behaves as a quasi-stationary random process, which is not especially "peaky" in either time or in frequency.

[7] It will be demonstrated that this is true regardless of the structure of the OFDM waveform.

2.1 Justification for White Noise Approximation for Total Interference

Since the thermal noise N_0 and the wideband signals are independent random processes, the Power Spectral Density ("PSD") of the total interference is the sum of the individual PSDs:

$$S_{tot}(f) = N_0 + S_{int}(f)$$

where $S_{int}(f)$ represents the interference PSD. However, the thermal noise is the dominant source of interference (at least 20 dB more power than the interference power), and hence the PSD of the total interference is very close to white. Thus, the total interference spectrum can be considered to be white noise:

$$S_{tot}(f) \approx N_0 + I_0$$

where I_0 denotes the average interference power level.

2.2 Samples of a Single Interfering Signal are Approximately Gaussian Distributed

The complex baseband representation for the transmitted signal consists of complex symbols modulating a wideband pulse train waveform with bandwidth W_1. The complex symbols are obtained from an Inverse Fast Fourier Transform ("IFFT") of independent and identically distributed complex data symbols drawn from a standard signal constellation (*e.g.*, QPSK or 8-PSK). The effect of this signal on a satellite channel with bandwidth W_2 (*e.g.*, W_2 = 128 kHz or 5 MHz) can be determined by passing the frequency-translated signal[8] through a band-limited receiver filter with bandwidth W_2 and sampling its output at the Nyquist rate of W_2 complex samples/sec. Filtering the signal in this way has two effects:

1. The tones that are outside the bandwidth W_2 are attenuated by the receiver filter, and only the tones within this bandwidth contribute significantly to the output samples. But as long as the number of tones that fall within the bandwidth W_2 is sufficiently large, the sum of the contributions from these tones will have a distribution close to that of a Gaussian random variable, via application of the Central Limit theorem.

2. The receiver filtering causes time-dispersion, or equivalently, inter-symbol interference ("ISI") in the received signal. The effect of time-dispersion is equivalent to having a pulse shaping waveform with larger time duration, with no change in the time interval between consecutive OFDM symbol blocks. Hence, the output samples at rate W_2 contain contributions from a large number of OFDM symbol blocks. As the amount of this contribution increases, the distribution of the interference becomes closer to that of a Gaussian random variable, again via application of the Central Limit theorem.

This intuitive reasoning can be formalized, and it is possible to derive a closed-form analytical expression for the filtered output samples at rate W_2 in terms of the data symbols transmitted on the OFDM tones. This expression does not yield additional special insight, but it can be used to verify the above two claims through simulation as shown via the following Examples.

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[8] The frequency translation accounts for the frequency difference between the center frequency of the wideband signal and the center frequency of the satellite channel with bandwidth W_2.

Example 1 (single OFDM signal with tone spacing = 15 kHz[9])

The transmitted OFDM signal has 1024 tones loaded with QPSK modulation symbols, and its bandwidth $W_1 = 15.36$ MHz. The tone spacing $\Delta f = 15$ kHz. Consider a satellite channel bandwidth of W_2 = 64 kHz. The complementary cumulative distribution function ("CCDF") of the envelope of the Nyquist rate (64 kHz) output samples relative to average power of the signal is shown in Figure 4 below. In this case, the major contribution to the interference samples is from the roughly $64/15 \approx 4$ tones within the satellite channel bandwidth W_2 = 64 kHz.

Notice that the tail of the interference sample distribution decays faster than that of a Gaussian random variable. In other words, the wideband interference does not have a higher peak-to-average ratio than that of a Gaussian random variable of the same power. Since the tail of the distribution is what determines the performance of a receiver for the narrowband satellite channel, treating the wideband interference as Gaussian distributed is a conservative approximation.

Figure 5, Figure 6, and Figure 7 below show the CCDF of the Nyquist rate output samples when the satellite channel bandwidth W_2 is increased to 128 kHz, 256 kHz, and 1 MHz, respectively. The number of tones that contribute significantly to the output samples is 9, 17, and 67 tones for 128 kHz, 256 kHz, 1 MHz, respectively. The Figures below show that as this number increases, the CCDF converges closer to that of a Gaussian random variable. Notice that in all the cases, CCDFs show that the output samples are less "peaky" than Gaussian random variable of the same power.

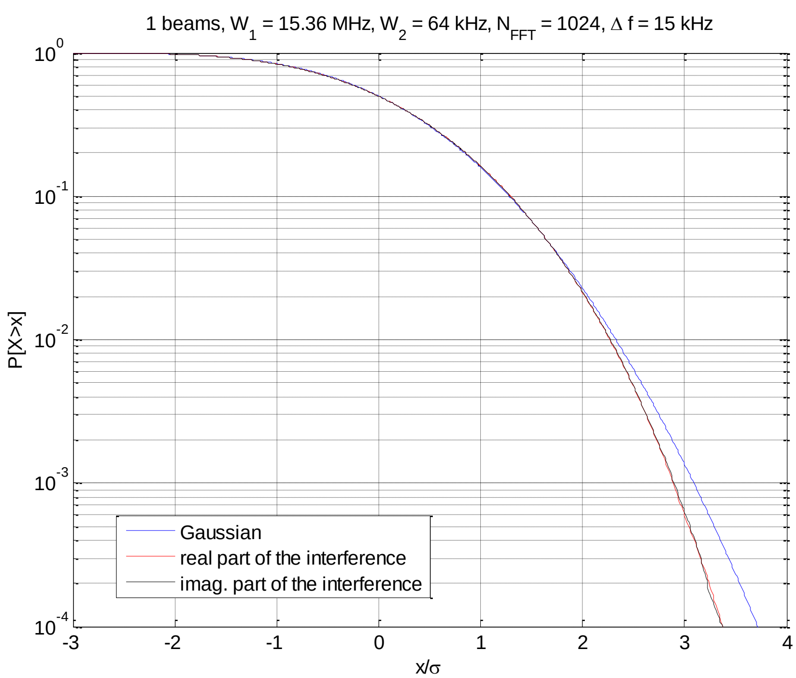

Figure 4. Single interfering OFDM signal. $\Delta f = 15$ kHz, W_2 =64 kHz

[9] In this example, a tone spacing that is used in LTE systems is chosen.

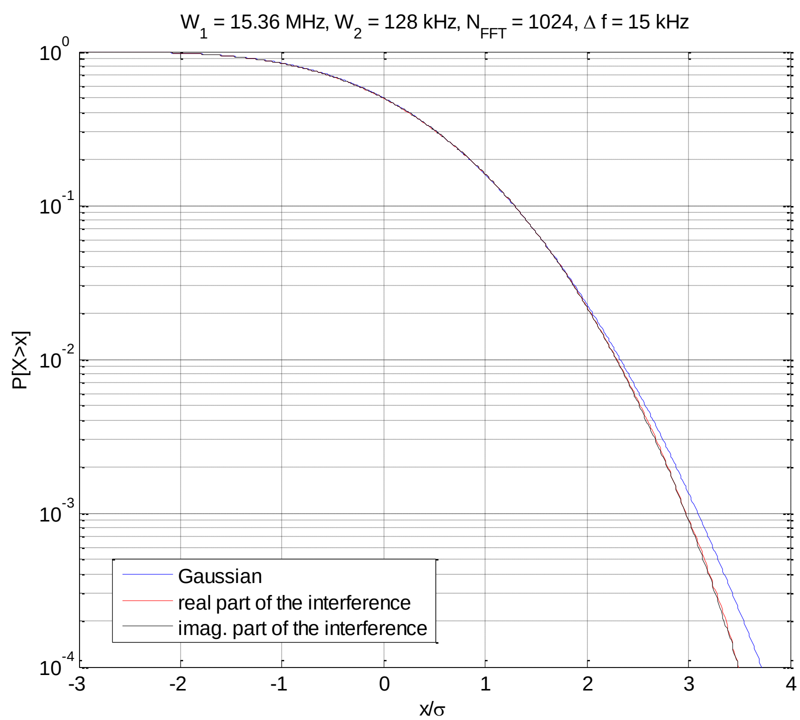

Figure 5. Single interfering OFDM signal. $\Delta f = 15$ kHz, W_2 =128 kHz

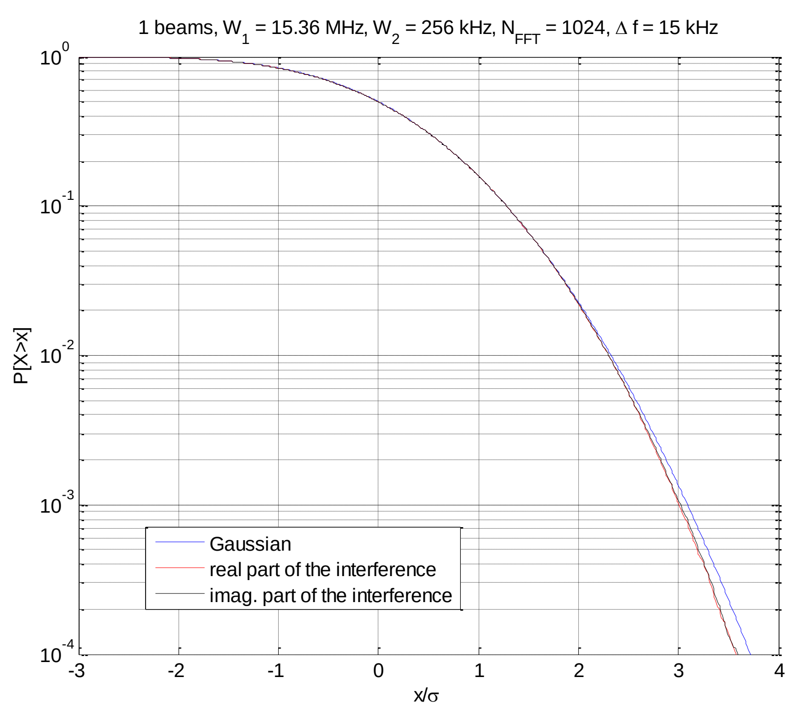

Figure 6. Single interfering OFDM signal. $\Delta f = 15$ kHz, W_2 =256 MHz

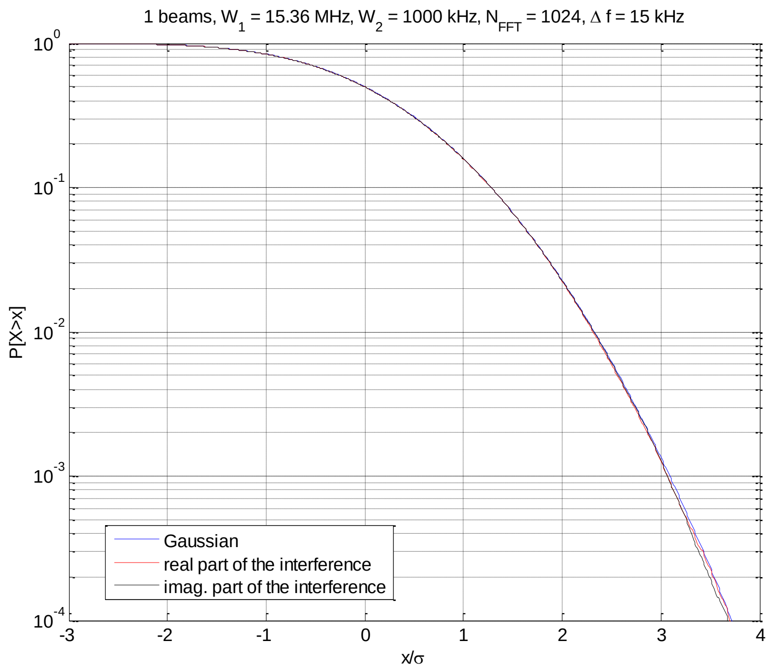

Figure 7. Single interfering OFDM signal. $\Delta f = 15$ kHz, W_2 =1 MHz

Example 2 (single OFDM signal with tone spacing =240 kHz)

As in Example 1 above, suppose the transmitted OFDM signal has bandwidth $W_1 = 15.36$ MHz. However, now suppose that the tone spacing is increased to $\Delta f = 240$ kHz from $\Delta f = 15$ kHz, or equivalently, suppose the number of tones is decreased from N=1024 to N=64. For satellite channel bandwidths of W_2 = 64 kHz, 128 kHz, 256 kHz and 1 MHz, the corresponding CCDFs are provided in Figure 8 through 11 below. With the increased tone spacing, the number of tones that fall within the satellite channel bandwidth is relatively small, and the more significant contributions in the interference samples are due to ISI from adjacent OFDM symbol blocks. Notice that in contrast to the previous example with $\Delta f = 15$ kHz, the smaller satellite channel bandwidth W_2 leads to a more accurate Gaussian approximation. However, as before, the interference samples are less "peaky" than a Gaussian random variable with the same power.

Accordingly, simulation Examples 1 and 2 demonstrate that *regardless of the tone spacing Δf or the number of tones N*, the interference process produced by a single GS beam (bandwidth W_1) has an approximately Gaussian envelope when viewed in any bandwidth $W_2 < W_1$. The samples of the interference process are approximately Gaussian distributed and are no more "peaky" than a Gaussian random process of the same power.

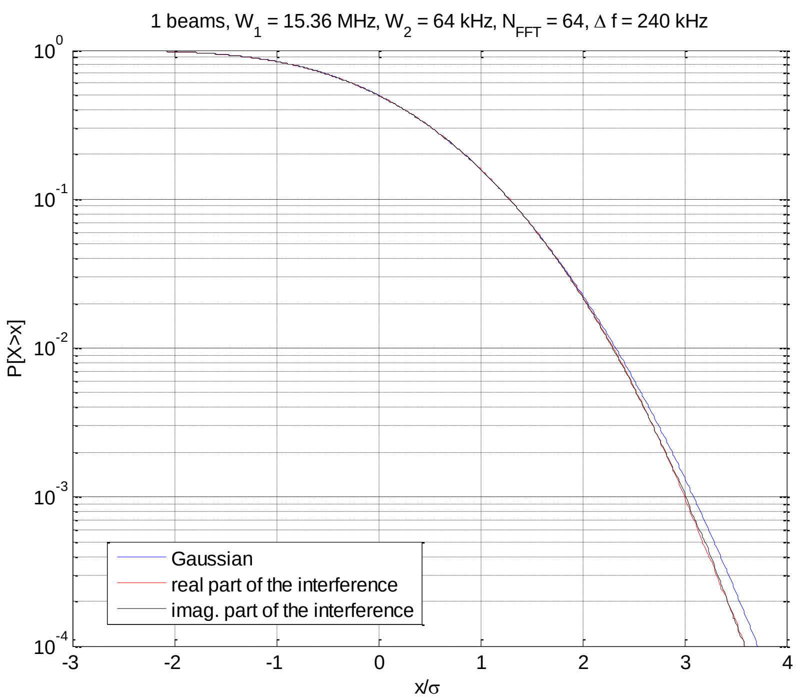

Figure 8. Single Interfering OFDM signal. $\Delta f = 240$ kHz, $W_2 = 64$ kHz

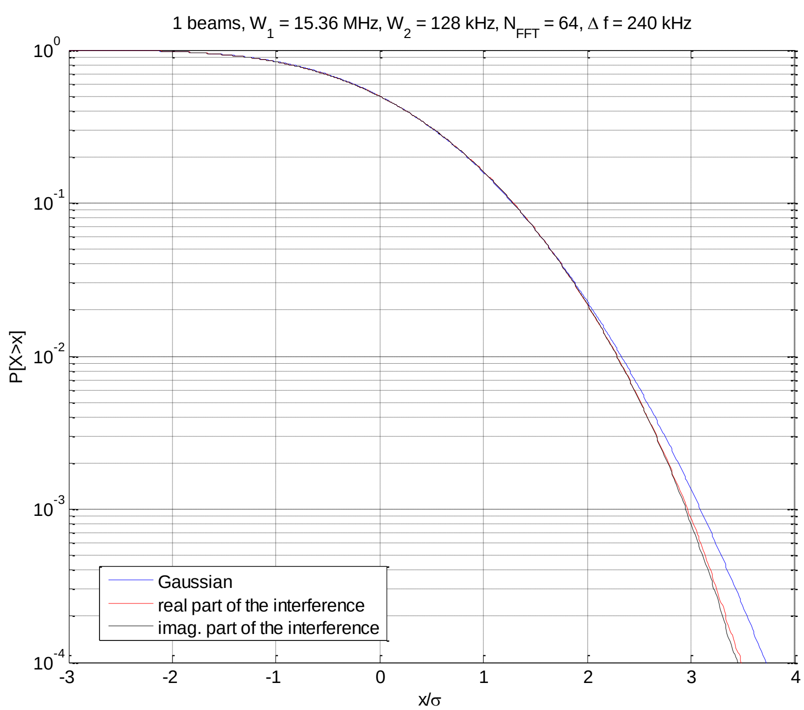

Figure 9. Single Interfering OFDM signal. $\Delta f = 240$ kHz, $W_2 = 128$ kHz

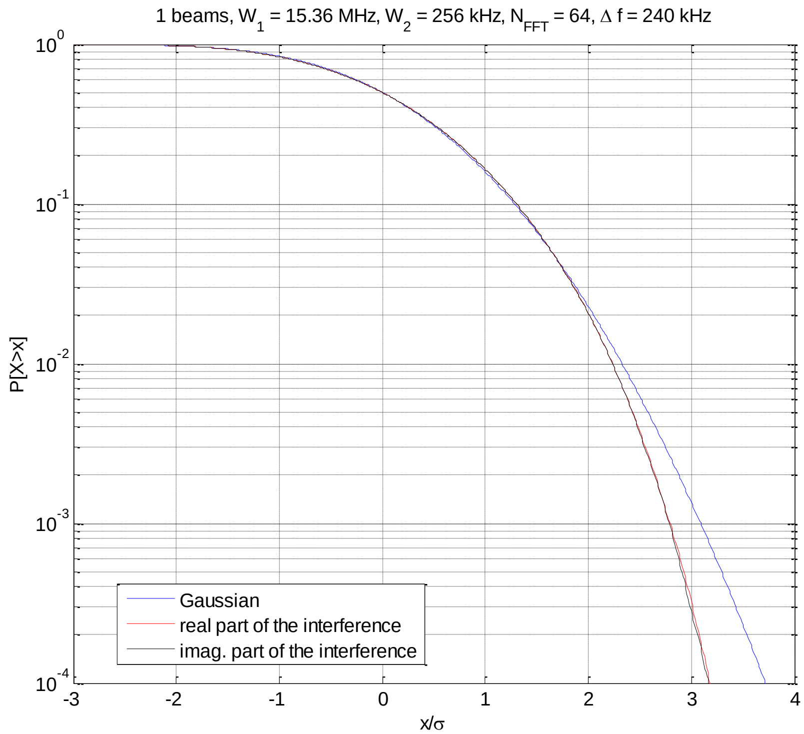

Figure 10. Single Interfering OFDM signal. $\Delta f = 240$ kHz, $W_2 = 256$ kHz

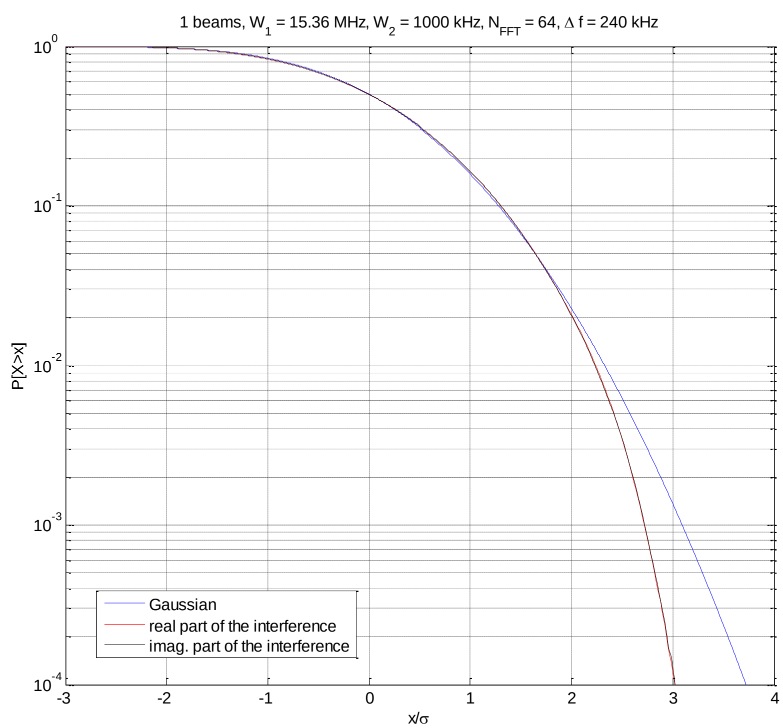

Figure 11. Single Interfering OFDM signal. $\Delta f = 240$ kHz, $W_2 = 1$ MHz

2.3 Samples of Multiple Interfering Signals are Approximately Gaussian Distributed

The satellite receiver in a bandwidth W_2 will typically see a superposition of multiple independent interfering signals from several beams belonging to multiple GSs. The interfering signals belonging to multiple beams from a single GS will be received at nearly the same power level. The signals belonging to different GSs will be received at different power levels determined primarily by the locations of the GSs within the satellite beam, and the relative G/T's at these locations in the beam.

Let M denote the number of independent interfering signals seen at the satellite antenna. Assuming the M interferers are of equal power, Figures 12 to 14 below show the CCDFs for samples of the composite interference, for M = 4, M=8, and M=12.[10] Note that the M = 8 case effectively assumes that the satellite beam's G/T is such that two GSs are seen at roughly equal power levels. The figures show that the composite interference samples closely approximate a Gaussian random variable even for relatively small values of M. For M as small as 12, the interference samples are virtually indistinguishable from a Gaussian random variable.

The observation that the CCDFs of the interference samples converge to a Gaussian CCDF is a specific demonstration of the Central Limit Theorem. This observation can be formalized and it is possible to invoke the multivariate Central Limit Theorem to conclude that the joint distribution of *any collection* of samples of the composite interference process at *any sampling times* is approximately multivariate Gaussian. This is the same as concluding that the composite interference signals are accurately represented by a Gaussian random process with the same average power.

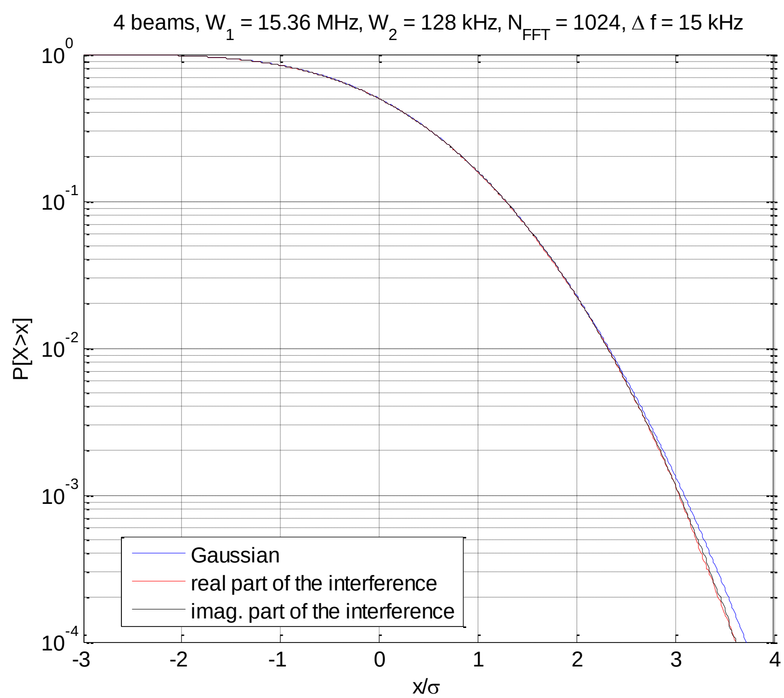

Figure 8. M=4 Interfering OFDM signals. $\Delta f = 15$ kHz, W_2=128 kHz

[10] For purposes of comparison, the corresponding case for M=1 is shown in Figure 5.

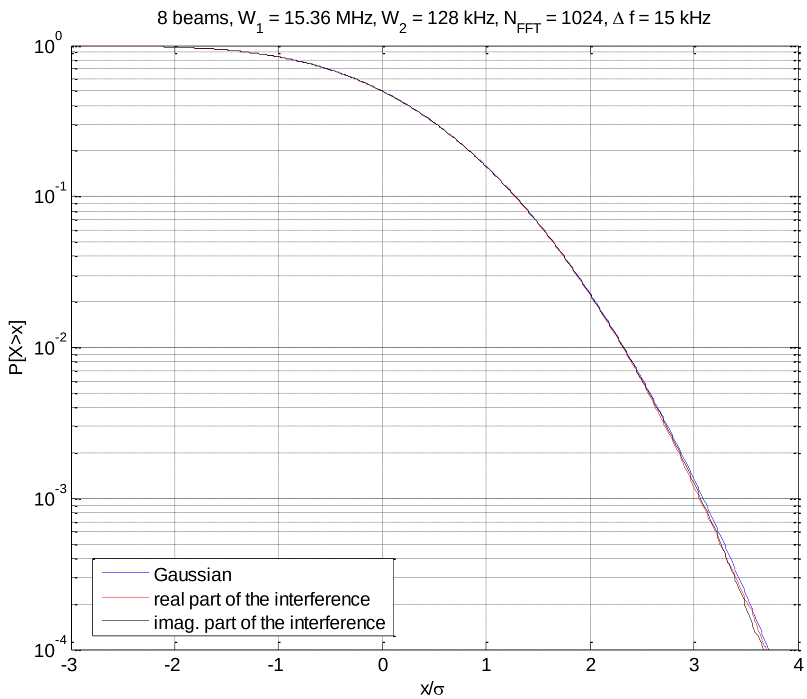

Figure 9. M=8 Interfering OFDM signals. $\Delta f = 15$ kHz, W_2=128 kHz

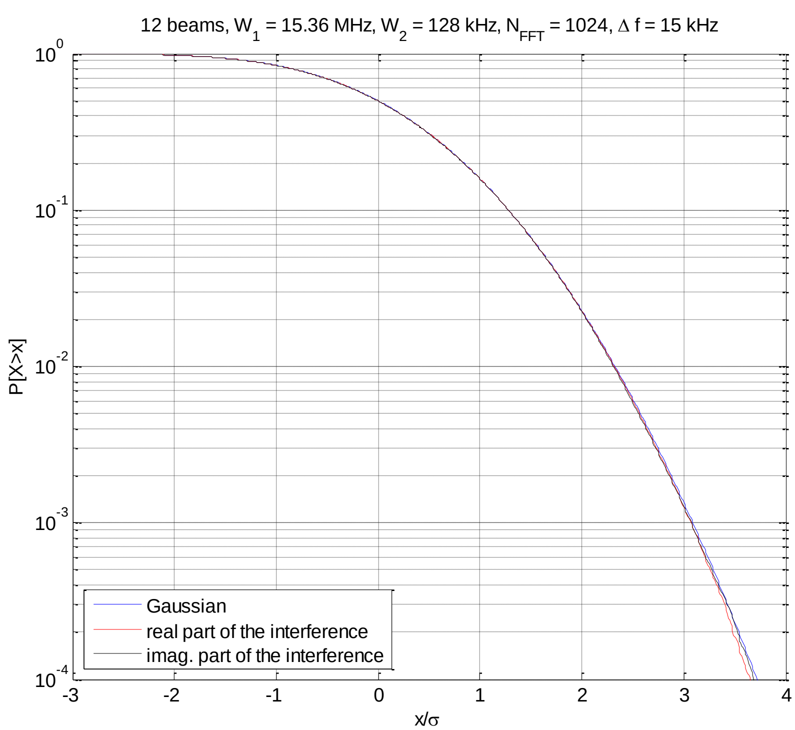

Figure 10. M=12 Interfering OFDM signals. $\Delta f = 15$ kHz, W_2=128 kHz

2.4 The Total Interference Process (Thermal Noise Plus Composite Interference) Is Effectively A White Gaussian Noise Process

As demonstrated above:

1. The total interference (thermal noise plus Next-Gen AG interference) is spectrally white in any bandwidth window narrower than the Next-Gen AG signal bandwidth;
2. Samples of the interference random process produced by a single GS beam are approximately Gaussian distributed;
3. Samples of the interference random process produced by a superposition of multiple beams from multiple GSs are approximately Gaussian distributed, and
4. The composite interference process is well approximated as a Gaussian random process.

In addition, it is known that:

- The thermal noise and the interference from Next-Gen AG signals are independent;
- The sum of two independent Gaussian random processes is itself a Gaussian random process, and
- The variance of the sum of two independent random processes is the sum of the respective variances.

Therefore, it follows that the total interference also is well approximated as a Gaussian random process. Hence, the effect of the interference on any satellite channel with bandwidth W_2 is only to raise the thermal noise floor by the average interference power.

3. Conservative Petition Interference Calculation Assumptions

This section describes a number of conservative assumptions that Qualcomm used in the interference calculations presented in Appendix A to the Petition and an estimate of the extent of the overestimation of the interference impact in the Petition due to each of these assumptions.

3.1 Polarization Assumption

The computations in the Petition assumed perfect polarization coupling between the aircraft and satellite antennas. However, due to the location of satellites in the geo-arc and the locations of the aircraft and GSs above the CONUS, the aircraft/GS and satellite antennas will not be perfectly aligned. If satellites use circular polarization antennas, then the power coupling of interference from the Next-Gen AG system is reduced by 3 dB. However, because most Ku band satellites use linearly polarized antennas, Qualcomm can estimate the amount of mismatch between the satellite and aircraft linearly polarized antennas by taking their respective locations into account.

In a linear-linear antenna coupling case, the local vertical-horizontal orientation of the earth surface to the GSO satellite can produce as much as 30 degrees of relative rotation of the aircraft linear polarization relative to the GSO satellite north orientation. However, many GSO satellites use additional rotation, *e.g.*, 26 degree rotation toward the east coast that favors service to the higher populated areas and relieves the ground equipment from having to be rotationally agile to produce perfect polarization alignment to the serving satellite.

For a satellite at 95 West with a satellite offset rotation of the linear feeds by 26 degrees to the eastern seaboard, the average total power coupling from aircraft/GS in different locations over the CONUS amounts to about -1.47 dB compared to the assumption of perfect antenna alignment between the satellite and all aircraft/GS over the CONUS.

Although a complete survey of satellite rotations has not been examined, a 1 dB reduction in interference due to misalignment of antennas can be expected.

3.2 Average versus Peak Backlobe Gain

In the Petition, the peak GS antenna backlobe gain was specified to be 0 dBi toward geo-arc, in ±90 degrees in azimuth and 100 to 170 degrees in elevation. In reality, however, in many angles toward the geo-arc, the antenna will be many decibels lower than 0 dBi in order to meet the peak gain of 0 dBi. Depending on aircraft location, beams from GSs are pointed toward a variety of azimuth directions. Therefore, the interference seen by the satellite uplink would be reduced by an averaging of the backlobe antenna gain to any satellite both from the mix of beam directions and the difference in azimuth directions from all GS locations on the CONUS. Even for a satellite spot beam whose coverage area sees only several GSs, there will be significant averaging of backlobe antenna gain because there are 4 beams in each GS and the beams in different GSs are pointing in generally random azimuth directions. Qualcomm's antenna design experts have calculated this average gain to be at least 5 dB less than the target requirement of peak 0 dBi gain. A separate computation for the sidelobe area in the geo-arc from the aircraft antenna finds that the transmit power toward geo-arc will be at least 5 dB less than the values used in the Petition.

3.3 Power Control Reduced Atmospheric Loss on Shorter Paths

In the link budget used in the Petition, 3 dB was allocated for atmospheric losses between the GS and aircraft where the aircraft is at the cell edge at 300 km from the GS. However, many aircraft will be located closer to the GS than 300 km. The atmospheric loss averaged over all aircraft locations is closer to an average of 1.8 dB. Therefore, with power control the transmit power will be, on average, at least 1 dB less than the maximum level used in the Petition.

3.4 Assumption of Full Traffic Loading of Beams

The calculations presented in the Petition assumed that all 4 beams in all GSs are transmitting 100% of the time. In other words, it was assumed that the buffers at the GS for each beam are always full of traffic. This would imply that the queues at each beam are never empty resulting in excessive packet queuing delays. However, in order to avoid long delays, in any queuing system the traffic that the system supports must be provisioned to be at considerably less than 100% utilization. A more realistic buffer loading will be about 75% to allow for providing practical delays. Hence, the buffers will be on average empty 25% of the time resulting in the beam being idle 25% of the time; the interference will be lower by 25%, *i.e*., 1.25 dB lower relative to the 100% loading assumption used in the Petition.

3.5 Traffic Profile Variation across CONUS

The calculations in Appendix A to the Petition assumed that all GSs across the CONUS carry an equal amount of data traffic. However, many GSs will carry a relatively small amount of data traffic because of light aircraft traffic in certain coverage areas. A coarse analysis of actual aircraft traffic in 200 km square grids across the CONUS reveals that the average aircraft traffic across all such square grids over the CONUS is less than half of the aircraft traffic in highest aircraft traffic sites in the east coast; that is, approximately 50% of the beams would be, on average, idle because they are in GSs that are in low aircraft traffic regions of the CONUS.

Recall that based on the calculations presented in Appendix A to the Petition, a minimum of 150 GSs are required for coverage across the CONUS. However, additional sites will be needed in the final network plan for coverage in certain locations because of terrain or geography, and to provide more capacity for high traffic areas. As discussed in Section 1 above, the power for the additional sites will be taken from the neighboring sites to ensure that the total emission into the geo-arc in each region of the CONUS remains constant. This implies that as much as 50% of the beams over the CONUS for the uniformly placed 150 site system analyzed in the Petition will not be used. In other words, the EIRP actually used by the GSs or aircraft will be at least 3 dB less than that used in the interference computations in the Petition.

3.6 Summary of Interference Overestimation Assumptions

The interference reduction from the term in Section 3.5 is obtained by averaging over the high and low aircraft traffic areas of the CONUS. Therefore, the benefit from the term in Section 3.5 holds for relatively large satellites beams that cover the entire CONUS or cover large parts of the CONUS. However, the interference reduction for terms in Sections 3.1 to 3.4 is obtained by averaging the corresponding variables over a small number of GSs. Thus, the interference reduction from terms in Sections 3.1 to 3.4 holds even for relatively small satellite spot beams that cover several GS sites.

For small satellite spot beams, the interference is overestimated by the sum of the terms in Sections 3.1 to 3.4 above, which is at least 8 dB. For large satellite beams, the interference is overestimated by the sum of the terms in Sections 3.1 to 3.5, which is at least 11 dB.

The above interference overestimation sums correspond to the average interference overestimation. However, because the final sums result from the addition of many beams and GSs and addition of different factors listed in 3.1 to 3.5, the variation from the mean will be rather small and the average values provided are reasonable estimates of the overestimation.

3.7 Satellite Beams at Low Elevation Angles

In the Petition, interference terms were included for GSs and aircraft that are at very low elevation angles of 5 degrees toward the satellites that would be located at the far east or west of the CONUS over one of the oceans. Those computations also did not include any atmospheric losses from GSs or aircraft to satellites. However, at such low elevation angles the propagation paths to the satellite will suffer from average atmospheric losses as well as perhaps blockages. Moreover, satellite beams that cover low elevations angles of say 5 to 10 degrees will have lower G/T over those regions and will see less interference than computed in the Petition assuming average beam G/T.